Enabling Cleanup Technology Transfer

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Abstract:

Technology transfer in the environmental restoration, or cleanup, area has been challenging. While there is little doubt that innovative technologies are needed to reduce the times, risks, and costs associated with the cleanup of federal sites, particularly those of the Departments of Energy (DOE) and Defense, the use of such technologies in actual cleanups has been relatively limited. There are, of course, many reasons why technologies do not reach the implementation phase or do not get transferred from developing entities to the user community. For example, many past cleanup contracts provided few incentives for performance that would compel a contractor to seek improvement via technology applications. While performance-based contracts are becoming more common, they alone will not drive increased technology applications. This paper focuses on some applications of cleanup methodologies and technologies that have been successful and are illustrative of a more general principle.

The principle is at once obvious and not widely practiced. It is that, with few exceptions, innovative cleanup technologies are rarely implemented successfully alone but rather are implemented in the context of enabling processes and methodologies. And, since cleanup is conducted in a regulatory environment, the stage is better set for technology transfer when the context includes substantive interactions with the relevant stakeholders. Examples of this principle are drawn from Argonne National Laboratory's experiences in Adaptive Sampling and Analysis Programs (ASAPs), Precise Excavation, and the DOE Technology Connection (TechCon) Program. The lessons learned may be applicable to the continuing challenges posed by the cleanup and long-term stewardship of radioactive contaminants and unexploded ordnance (UXO) at federal sites.

Keywords:

Cleanup technology, adaptive sampling and analysis, precision excavation, Triad, Technology Connection

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Introduction

The cleanup of the legacy wastes from federal activities in the United States during the Cold War is a large and expensive environmental problem [1]. The nation has expended more than $100 billon to date on environmental restoration, and these cleanup activities are expected to continue for more than 25 years into the future at some of the more complex cleanup sites. Costly and time-consuming challenges of this magnitude generate considerable motivation for the development and implementation of new technologies and innovative approaches. Indeed, the cleanup program in the United States has dedicated significant resources to the development of new technologies for the characterization and remediation of contaminated media.

The range of cleanup technology development activities is impressive and reflects funding in excess of $200 million per year for several years [2]. New developments have included characterization tools for determining the extent of contamination, particularly in the subsurface, active remediation technologies such as soil washing and thermal treatments, and, more recently, passive remediation technologies such as bioremediation and phytoremediation. Many technologies have been taken from pilot study phases into field demonstrations. Several programs, such as the U.S. Environmental Protection Agency's (EPA's) Superfund Innovative Technology Evaluation (SITE) program [3], and the Department of Energy's (DOE's) Technology Deployment Initiative [4], were established to evaluate technologies and in so doing promote their adoption by the cleanup community. While many new approaches and technologies have found their way into the cleanup business, many more have not. There has been a significant amount of dismay that deployments have been relatively limited. Traditional methods of "hogging and hauling" contaminated soil for disposal elsewhere and of "pumping and treating" contaminated groundwater seem to be employed routinely, although alternatives may be available to reduce the environmental risks at the same or lower costs.

There are, of course, many reasons why technologies, in general, do not reach the deployment phase or do not get transferred from developing entities to the user community. In addition to the usual impediments to technology deployment, such as funding through the "valley of death" phase between early prototypes and full-scale demonstration, there are factors that appear unique to the environmental restoration arena. These factors and examples of some successful applications of innovative cleanup methodologies and technologies are the focus of this paper. The examples are illustrative of a general principle that is at once obvious and not widely practiced. It is that, with few exceptions, innovative cleanup technologies are rarely deployed successfully alone but rather are deployed in the context of enabling processes and methodologies.

Challenges to Innovative Technology Deployment in Cleanup

The factors associated with environmental cleanup that have impeded the widespread application and transfer of innovative technology are technical, regulatory, strategic, and institutional. Efforts have been directed at each of these areas to remove barriers and to encourage innovation.

Technically, many cleanup problems are very difficult. Processes related to the behavior of contaminants in the natural environmental are complex, and the fundamental understanding of most of them is quite limited. Because environmental media are heterogeneous and anisotropic at several spatial scales and contaminant transformation processes operate at varying temporal scales, development of general predictive tools has been slow. In addition, the complexity of the environment makes the extrapolation of cleanup experience from one location (even within the same facility) to another risky. Particularly challenging is the subsurface environment, in large measure because of its limited accessibility for both improved understanding of basic processes and sampling to determine the extent of contamination or progress of treatment. The impacts of our deficient understanding and research needs for subsurface science as it relates to the DOE's cleanup program were examined in a recent study by the National Research Council [5]. Perhaps the most significant scientific and technical factor is our imperfect understanding of, and limited prediction capability for, the assessment of risks to human health and the environment from contaminants. This lack creates a fundamental uncertainty that has both direct and indirect consequences on the introduction of innovative technologies into the cleanup.

The myriad of federal and state regulations have had intended and unintended effects on the implementation of innovative cleanup technologies. While rarely specifying technology solutions to cleanup problems, these regulations have identified "presumptive solutions" for some of the more commonly encountered problems. More importantly, some practices in the cleanup community derived from the cleanup decision processes indicated in the Comprehensive Emergency Response, Compensation, and Liability Act (CERCLA) and in the corrective action portion of the Resource Conservation and Recovery Act (RCRA) have worked against the original intent of these Acts (see Reference 6 for further discussion of these decision processes). These practices tend to emphasize a series of "feed forward" studies leading to the choice of cleanup technology instead of studies to support "feedback" decision making. "Standard" technologies are often selected because inadequate data and information are available to support a more innovative alternative. In addition, the public and other stakeholder groups can exert considerable pressure on regulators and cleanup problems holders to "do something now" and "provide a low-risk solution." Such pressures seldom lead to the application of new approaches. Much of the regulatory debate in cleanup still revolves around the risk question of "how clean is clean?" and the addition of innovative technology into the decision process is often viewed as simply compounding the uncertainties.

As cleanup activities progress from early characterization phases to the implementation of a remedy (or remediation phase), strategic decisions arise that may affect choices of technology. One such decision relates to "getting done as quickly as possible." Cleanups of major federal facilities are expensive, and there is continual encouragement to finish the job. Consequently, cleanup contractors are often "incentivized" to complete remediation to regulatory satisfaction as rapidly as possible. In the majority of cases, residual contamination will remain, and it will require future management. The costs and risks associated with the long-term stewardship of this residual contamination are not insignificant and are related to monitoring, maintenance of barriers and other remedies, and information management [7]. The drive to get the cleanup "done" has, in most cases, ignored the life-cycle costs of these stewardship activities and has not accounted for the potential cost-reduction effects of innovative technologies introduced during remediation. Consideration of the long-term strategy for a site may improve the opportunities for new approaches.

The regulatory community has had to balance its responsibilities to protect human health and the environmental by proceeding cautiously with the approval of innovation cleanup technologies and its interest in promoting the use of technologies that will do a "better" job of cleanup. These purposes have occasionally conflicted to inhibit attempts at innovative technology deployment, but usually the issues have revolved around questions of technology performance. The EPA has sought to assist the cleanup community by providing sources of information on cleanup technologies, conducting demonstration projects, and evaluating technologies through its SITE and Environmental Technology Verification (ETV) Program. The Federal Remediation Roundtable, in which EPA participates, provides similar support by drawing on the resources and experiences of several federal agencies, including the DOE and the Department of Defense with their large cleanup programs. Concerns about regulator interest in new technologies implying "endorsement" and about regulator evaluations being properly caveated to reflect the conditions under which testing occurred have limited the range and effectiveness of regulator-supported technology implementation.

The primary impediment to the application and transfer of technologies in cleanup is, however, related to institutional issues within the organizations responsible for the cleanups. A General Accounting Office (GAO) study [8] of the tendency in DOE to choose conventional approaches over innovative ones identified causes that included:

- Fear that using new technologies may lead to missing project milestones,
- Unfamiliarity with innovative technologies on the part of site officials, and
- Reliance of officials on recommendations from site contractors who may favor particular technologies on the basis of their own experiences and investments.

In addition, performance-based contracts for cleanup, while in principle opening the door to new approaches, incentivize work completion and deadlines in ways that do little to reduce these barriers.

In recent years, several new programs and/or modifications to existing programs have emerged that confront several of these challenges. For example, the Strategic Environmental Research and Development Program (SERDP) has focused some of its funding on improved understanding of the behavior of, and performance of technologies for the treatment of, dense nonaqueous phase liquid (DNAPLs) in groundwater. In addition, the Environmental Security Technology Certification Program (ESTCP) focuses its projects on the demonstration of technology in the context of on-going cleanup activities. The DOE created a "deployment initiative" to foster greater understanding of the benefit of deploying innovative technologies and created a technical infrastructure to assist in the deployments. Regulators from 35 states form the core of the Interstate Technology Regulatory Council (ITRC) along with multiple other federal partners, industry representatives, and stakeholders in a cooperative effort to "…break down barriers and reduce compliance costs, making it easier to use new technologies…" The EPA Technology Innovation Office has undertaken a number of communication, education, and demonstration projects directed at improving technology deployment.

The successes being realized in these recent efforts are due in large measure to the emphasis on a wider view of technology. Technology is no longer treated in the abstract, particularly not as "a solution in search of a problem." Indeed, significant attention is given to the enabling processes and methodologies that integrate cleanup technologies into the larger cleanup activity.

Enabling Processes and Methodologies

It should be no surprise that the introduction of new technology into an enterprise as complex as the cleanup of a large federal installation is not simple. The competing factors of institutional inertia, regulatory concerns, and incentives to accelerate cleanup only reinforce existing barriers. The processes that have been successful in removing or circumventing the barriers to introduce new technologies account for these complexities. They treat technology selection as part of larger decision-making process within the cleanup framework and not as an isolated entity. By embracing this more holistic approach to cleanup problems, "technology" becomes embedded with other solution approaches that, in the end, enhance the prospects for appropriate innovative technology to be applied. These enabling processes (which can also include methodologies and technologies) can "pull" innovative technology into acceptance.

While these enabling processes may vary from case to case, they have these common attributes:

- Provide a broad cleanup context for the technology,
- Relate clearly to a well-defined end state of the cleanup,
- Involve multidisciplinary considerations (such as risk), and
- Engage problem holders with regulatory and other stakeholders in the decision process.

Two examples from experiences in Argonne National Laboratory programs that assist the cleanup of federal sites illustrate the importance of such enabling processes. The first example concerns the introduction of a new enabling methodology that not only created a significant change in the way sampling and analysis were conducted, but also helped to pull a suite of field analytical instruments and methods into acceptance. The second example relates to a process aimed at connecting cleanup problem holders with specific innovative technologies and fostering the deployment process.

ASAP, Precise Excavation, and Triad

Standard practice within the cleanup community for many years was that soil at a cleanup site was sampled and the samples were sent to a certified laboratory for analysis for potential contaminants. In most cases, soils were sampled at regular intervals along preplanned grids. The results of the laboratory analyses were expected to be of high quality but were often unavailable for several weeks. When such sampling and analysis were in support of characterizing the extent of contamination or of a remedial action, decisions associated with the interpretation of data were delayed by the process. Typically, the results of initial sampling did not adequately capture the extent of contamination, and additional sampling was required. Subsequent sampling and analysis required a remobilization of field sampling crews and equipment, followed again by the delay in getting results back from laboratory analysis. Several obvious problems were associated with this practice:

- Characterization activities took a long time,
- Laboratory analyses, while generally of high quality, were expensive as well as time consuming, and
- Despite repeated sampling campaigns, the delineation of the extent of contaminated soil and estimates of the volumes of contaminated soil were poor.

During the past 10 years, while the standard practice continued, a group of technologies was advancing that offered relief for many of these sampling and analysis problems confronting the cleanup efforts – field analytical instruments. New electronics and miniaturization, among other advances, were producing a wealth of alternatives to sending every soil sample off-site to a laboratory for analysis. In 1994, Moore [9] summarized both the many new instruments available and the apparent barriers that had frustrated their widespread use. Much of the concern at that time was focused on whether field analytical instruments were able to deliver results of the same quality as laboratory analysis. It would take a paradigm shift in the way sampling and analysis were viewed to have the focus change from laboratory analysis quality to overall decision uncertainty and to create the emerging acceptance of field analytical instruments.

The methodology that enabled field analytical instrumentation to be applied more extensively in cleanup activities was a new approach to sampling and analysis. It broke dramatically with the practice of preplanned gridded sampling followed by analysis of samples at an off-site laboratory by creating an "adaptive" approach. This adaptive approach, or Adaptive Sampling and Analysis Programs (ASAPs) as coined by Johnson [10, 11], used the results of initial sampling and analysis to drive subsequent sampling, with the goal of minimizing the uncertainty associated with the extent and volume of contaminated soil and the number of samples collected. Underlying geostatistical and Bayesian analyses of the data collected permit such "value of information" assessments to be made to guide the sampling. This adaptive approach, for example, limits repeated sampling in areas that are clearly contaminated at concentration levels that will require action and encourages sampling in areas that have not been identified as either contaminated or "clean." Thus, the process of adaptive sampling uses prior results to converge the sampling rapidly to delineate contaminated soil volumes.

Not only is this strategy for sampling more efficient than preplanned sampling, but it also creates opportunities for field analytical instrumentation for two important reasons:

- Data for the adaptive approach do not all have to be at the same level of uncertainty (i.e., quality) to have value in decision making,
- The iterative nature of the "value of information" analysis of sampling results provides an incentive for rapid data updates to guide the sampling.

Field analytical instrumentation can provide obvious contributions to this approach because the requirement for all data to be of laboratory quality has shifted. Simply known precision and accuracy for field instrumentation may in many cases permit a mixture of field instrument results with selected laboratory analysis to be sufficient to characterize the extent of contamination to guide cleanup activities.

It is important to note that adaptive sampling and analysis programs do much more than simply replace laboratory analysis with field analytical instrumentation. Because they are focused on defining the extent or volume of contamination, they require *a priori* consideration of what levels of contamination will drive further action (such as a risk assessment or soil removal). It is these broader considerations that help determine whether field instrumentation detection levels will be adequate for the characterization, and to what degree they should be combined with laboratory analysis. The likely reduced quality of field instrumentation data versus that of laboratory analysis is now raised in the context of uncertainty in the volume of contaminated soil. This consideration refocuses the data quality question from the laboratory analysis to one of sample representativeness. Despite the fact that common practice primarily addressed the uncertainty associated with the analysis of a sample, it was well known that the largest contribution to uncertainty in determinations of the extent of contamination was spatial variability in the samples. While compositing and other sampling schemes sought to address this source of uncertainty, it seems that only examining the overall uncertainty in decisions about volumes of contaminated soil has brought the discussion of the quality of analysis into perspective. The advantages of having larger amounts of lesser quality data become readily apparent. The ability of field instrumentation to support rapid and inexpensive sampling of large spatial domains with concurrent, or subsequent, confirmation with fewer laboratory analyses led to better characterization at significant cost savings over traditional methods (in Argonne's experience, savings are at least 50%).

The details of an early ASAP application related to characterizing the extent of explosives contamination of soil at a former Army manufacturing facility [11] provide an interesting example of how field observations with quite different levels of certainty can contribute to the adaptive sampling. A field portable GC/MS provided relatively high-quality on-site analyses to facilitate significant sampling, but information from visual observations of TNT-stained soil enhanced the adaptive process as well.

The fact that soil contaminated with radiological constituents can be often detected relatively easily with field instrumentation has led to many applications of ASAP approaches at such sites. Indeed, where the radiological constituents of concern (or surrogate isotopes) are detectable with walkover (or vehicle-mounted) instruments, the opportunity exists to get almost complete surficial coverage of a site. Typically, a global positioning system (GPS) device provides location data which are integrated with the disintegration "counts" from radiological measurement device to produce almost continuous spatial coverage of relatively large areas. Several ASAP applications with radiological and nonradiological contaminants and a variety of field analytical instrumentation are examined in a DOE innovative technology summary report on ASAPs [12].

The ASAP approach has moved from characterization activities into soil remedial actions involving excavation, opening the door farther for additional deployments of field analytical instrumentation. The removal of subsurface contaminated soils by excavation generally has been by block excavation. That is, the surface "footprint" of the contamination together with sparse boring information on its depth was used to define a "block," which was removed following pre-excavation delineation. Consequently, it was typical for much "clean" soil to be removed as waste and for subsurface pockets, or lenses, of contaminated soil outside the surface footprint to be discovered only after the block was removed. In cases where disposal costs are high, such as for radiological contaminated soils, the penalties for disposal of clean soil are high. Thus, together with the U.S. Army Corps of Engineers, Argonne devised a process of "precise excavation" in which excavation takes place in small "lifts" from the surface down, followed by rapid radiological soil surveys of the lowered surface with field instruments interpreted with an ASAP analysis to determine the next footprint for excavation. The decision process is enhanced by the rapid acquisition and analysis of data that guide the excavation activities. Sometimes, excavation can continue on one half the site while radiological measurements are being made on the other half.

Field radiological and position (GPS) data are acquired data loggers during walkover surveys and are then transmitted over the Internet to Argonne for analysis (contaminant location and uncertainty analysis). Completed analyses, including maps of the next excavation at depth, are transmitted back to the field, and surveying moves over to the previously excavated area. The rapid acquisition and analysis of data and display of analysis results on a secure web site permits disparate decision makers (including stakeholders) to monitor and direct the excavation decisions.

An application of the precise excavation approach at a radiologically contaminated site in the State of New York, Ashland 2, by the U.S. Army Corps of Engineers and Argonne resulted in considerable cost savings [13]. In an independent cost analysis, the DOE concluded that the actual precise excavation of the site cost about $18 million compared with an estimated cost of $36 million for traditional block excavation [12]. Moreover, the additional costs of the application of field instruments in continual walkover surveys and the regular analysis of data before each excavation lift totaled about $200,000, thus providing a benefit-to-cost ratio of about 90:1 for this innovative approach.

The positive impact of Argonne's ASAP and the expedited site characterization activities of others have caught the attention of the EPA. While EPA guidance to cleanup contractors in the past never prohibited such approaches, earlier concerns about field analytical instruments and considerable focus on the quality of analytical laboratory results seem to have occupied its attention. However, EPA's Technology Innovation Office recently has embraced a holistic view of the management of data uncertainly as it affects environmental decision making. It places renewed emphasis on sample representativeness and on the role that field instruments, together with laboratory analyses, can play in reducing uncertainty [14]. Indeed, the EPA has developed an approach for improving sampling, analysis, and data management for site characterization and cleanup. It calls the approach "Triad" for the three core principles of "systematic planning," "dynamic work plans," and "on-site measurement technologies" [15]. In addition, recently developed guidance for surveys of surficial radiation contamination, the *Multi-Agency Radiation Survey and Site Investigation Manual* (MARSSIM) [16], emphasizes the connections between field measurements and the reduction of decision uncertainty.

EPA's activities to educate the cleanup community about the benefits of the "Triad" approach will undoubtedly meet resistance of some who will have difficulty changing from past practices, but the common sense logic that it provides concerning data uncertainty will be welcomed by most. Moreover, the use of field analytical instrumentation will increase markedly. That will happen not just because a regulator acknowledges its value, but rather because an importance context has been provided. Field analytical instrumentation will be deployed because the enabling processes of adaptive sampling and "Triad" create a powerful rationale for it.

Technology Connection – Another Enabling Process

The DOE was concerned that officials with site cleanup problems be made aware of potential solutions afforded by innovative technologies that had been deployed successful elsewhere at private site cleanups or other federal locations. To ensure the dissemination of this information, Argonne assisted the DOE with the creation of a project that became known as the "Technology Connection" program to meet that need.

In the early stages of this program, considerable effort went into identifying candidate cleanup technologies and understanding the cleanup needs of DOE sites across the nation. The identification process went well beyond the typical cleanup technology database approach. Effort was expended in "due diligence" with the vendors of technology, seeking verification of the operating conditions and regulatory approvals associated with successful deployments, and confirming the performance of the technology. On the "needs" side of the problem, DOE site cleanup managers were interviewed about their selection criteria for technology solutions to site cleanup. A number of candidate technologies were then identified in response to those discussions. The "connection" part of the process consisted, in simple terms, of pairing qualified vendors of technology with DOE problem holders, often in a meeting setting. Several of the initial pairings did not lead to the technology deployment anticipated, despite what appeared on the surface to be a "good match."

Retrospective analyses of the "failures" of the early pairings revealed that "connections" were not enough for technology deployment to result. While the program had addressed a number of the barriers associated with the introduction of innovation technology, it became clear that it was not sufficient for the program to pick solutions. Several ingredients to support deployment of the technology were missing:

- Many problem holders, and their contractors, were not experienced in dealing with the types of innovative technologies provided,
- Most vendors of innovative technology were not experienced in working at large federal cleanup sites,
- Stakeholder education and "buy in" had not been accomplished, and
- On occasion, problem holders' desires for technology solutions were not necessarily supported by complete characterization of their contamination problem.

As a result of this examination, the Technology Connection program reorganized its approach and developed an enabling process that led to several successful technology deployments. The principal feature of the revamped process was that the Technology Connection technical staff began working with the problem holder and technology vendors involved in the "connection," serving as a catalyst and trusted advisor for the final technology decision making. They organized "workshops" at which prescreened candidate vendors were brought together with problem holders to discuss initially not their technology desires but rather the site's contaminant problems. Eventually the workshops, which now include regulators and stakeholders in addition to technical experts, would focus on technology solutions. By creating the larger context in which technology was not viewed as an abstract piece to the cleanup puzzle but rather as an integral part of the large cleanup decision, appropriate deployment resulted.

The efficiency of the Technology Connection enabling process improved dramatically in recent years as web-based tools were employed to the advantage of the problem holder, technology vendors, and the "connection" technical assistance team. A web site [17] was used to provide detailed background information on a site's contamination issues (e.g., mercury contaminated soil) and cleanup objectives to technology vendors. Those vendors with candidate technologies were then able to submit electronically their capabilities and records of experience specifically addressing that problem. As that information was made available to other vendors, there were opportunities before any workshops were held for integration of complementary technologies (as well as the unintended, but useful, feature of self-policing of vendor claims). Consequently, invitees to workshops were limited to those technologies "prequalified" by their prior deployments, and workshops were very focused on the specific site problems.

Conclusions

As site cleanup activities have progressed over the past 15 years, the estimated costs of protecting human health and the environment through restoration have increased. Technologies have been held up on many occasions as the primary means to reduce the costs and risks associated with cleanup. In many cases, deployments of technology have not been realized despite much promise for success. As the cleanup activities become complete at some sites, the costs of the long-term stewardship of residual contamination are being evaluated. Improvements in technologies for monitoring, leak detection, and information management may provide a means to reduce the potentially large mortgage costs associated with the on-going responsibility for residual contamination. The issue of the cleanup of unexploded ordnance (UXO) at military ranges and training areas presents new challenges of detection and removal. Again, the costs and risks of cleanup for unrestricted use with current techniques is prohibitive in all but a few instances. Significant advances in UXO cleanup technologies will be required.

The primary lesson of innovative technology deployment and transfer in the cleanup of major contaminated sites is that high-quality technology is necessary but not sufficient. Innovative technology is not utilized to its fullest without the appropriate enabling processes and methodologies. Cleanup actions are complex, and potential implementers of technology should become cognizant of the enabling techniques that can provide the context for technology deployment.

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